RESPONSIVE MOVEMENT AND g(0) FOR TARGET SPECIES OF RESEARCH VESSEL SURVEYS IN THE EASTERN TROPICAL PACIFIC

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APRIL 2002

ADMINISTRATIVE REPORT LJ-02-02

ABSTRACT

The most recent round of line-transect surveys to estimate cetacean abundance in the Eastern Tropical Pacific (ETP) was conducted by the Southwest Fisheries Science Center (SWFSC) over a three-year period from 1998-2000. These methods assume that animals do not react to the ship before they are sighted and all animals on the trackline are detected. To test these assumptions, five data sets were analyzed. Two types of independent observer sightings were tallied by species and divided by the number of comparable primary team sightings to estimate a percentage of schools missed on the trackline. It appears that g(0) for the target species of this survey is very close to 1.0 (0.964 and 1.0 depending on the data set). Observer estimates of school speed and direction, resightings and school positions recorded by a helicopter prior to the schools being sighted by the ship were investigated for evidence of responsive movement. There is some indication of responsive movement from the swim direction data, but the conclusions are often contradictory depending on which methods are employed to test the data. Relative motion plots do not indicate a consistent pattern of responsive movement to the vessel prior to sighting for offshore spotted, eastern spinner and mixed offshore spotted/eastern spinner schools.

INTRODUCTION

A fundamental assumption of distance sampling is that the objects of interest are detected at their natural density in relation to the transect line. Several techniques have been proposed for evaluating and dealing with responsive movement, but these generally rely on information from two independent sets of observers or platforms (Buckland and Turnock, 1992); (Borchers *et al.*, 1998); (Palka and Hammond, 2001).

Estimates of abundance of spotted and spinner dolphins in the eastern tropical Pacific (Gerrodette and Forcada, 2001) were based on data collected with a single set of observers, and therefore assumed that there was no responsive movement of the dolphin schools before detection. Previous studies of movement in these species using helicopters has shown some evidence of movement at large distances (Au and Perryman, 1982), but that most dolphin schools were detected before they reacted to the research vessel (Hewitt, 1985). In this report we summarize data collected on cruises in the eastern tropical Pacific in 1998-2000 that provide additional data on possible responsive movement for these species.

Another assumption of a single platform survey is that all animals are detected on the trackline. In the usual notation of line-transect analysis, g(y) is the probability that an object at perpendicular distance (y) from the trackline is detected, and this assumption is therefore expressed as g(0) = 1. We also present data collected on the 1998-2000 surveys to evaluate this assumption for dolphins seen on these cruises.

METHODS

Large-scale surveys to estimate the abundance of spotted and spinner dolphins (*Stenella attenuata* and *S. longirostris*) affected by the purse-seine fishery for yellowfin tuna (*Thunnus albacares*) were carried out in 1998, 1999 and 2000. Field methods are described in Kinzey *et al.* (2000). Observers searched with large marine binoculars from an eye height of 10.4 – 10.7m from sea level. From this platform, the horizon is approximately 6.3nm, and the largest effective sighting distance is about 4.5nm. We pooled several kinds of data collected on these cruises to evaluate the assumptions that g(0)=1 and that there was no responsive movement.

Birder sightings

During all periods when marine mammal observers were searching the trackline, a bird observer was simultaneously conducting seabird transects within 300 m on one side of the trackline. If the birder saw a school of dolphins, the position of the dolphins was noted and, if the school was not seen by the marine mammal observer team by the time the school was abeam of the ship, the school was recorded as a missed sighting. No record was kept of schools seen by the bird observer but subsequently detected by the mammal observers. Sightings of spotted, spinner, common and striped dolphins were compared. Bird observers only searched one side of the trackline so we multiplied the number of missed sightings by two. Finally, we took 1 minus the ratio of missed dolphin sightings to total dolphin sightings (birder + primary team) within 300 m of the trackline as a simple estimate of g(0).

Tracker data

In 1998 on one ship, the *Endeavor*, one observer was stationed high on the mast (7 m above the primary observer team) and equipped with 25X binoculars. When this observer detected a school of dolphins before the primary team detected it, he/she recorded the angle and distance to sighting. Sightings of spotted, spinner, common and striped dolphins were compared. As with the birder sightings, we took 1 minus the ratio of missed dolphin sightings to total dolphin sightings within 300 m perpendicular to the trackline, while the tracker was on effort as a simple estimate of g(0).

Observer estimates of initial swim speed and direction

At the time of each dolphin sighting, the angle relative to the trackline and radial distance to the school were recorded. Together with the ship's heading, this allowed a calculation of the position of the school relative to the ship at that time. Observers also attempted to estimate swim speed and direction at the time of sighting. We graphed these estimates of swim speed as a function of radial distance to the sighting by species, and explored the estimates of swim directions for evidence of responsive movement using a

Rayleigh test (Zar 1999) and the ‘quadrant method’ described in Palka and Hammond (2001). For both techniques, starboard sightings were “folded over” onto the port side for consistency. Results are presented as if all sightings occurred on the port side of the trackline. Swim directions are measured relative to the trackline for both methods. For example, a swim direction of 0 (or 360) degrees would correspond with a school swimming in a parallel heading to the ship’s, a swim direction of 90 degrees would be swimming straight towards the trackline while 270 degrees would be straight away from it.

The null hypothesis of the Rayleigh test is that swim directions are randomly distributed with respect to the trackline. To test this we must first calculate the mean angle, Â, of our sample. Given n angles, a1 through an, the rectangular coordinates of the mean angle are:

$$X = \frac{\sum_{i=1}^{n} \cos a_i}{n}, \tag{1}$$

and

$$Y = \frac{\sum_{i=1}^{n} \sin a_i}{n}. \tag{2}$$

We then calculate, R, a unitless measure of angular dispersion:

$$R = \sqrt{X^2 + Y^2}, \tag{3}$$

where R=0 represents so much dispersion no mean angle can be calculated and R=1 indicates all swim directions are concentrated in the same exact direction. Even if swim directions are randomly distributed, it can be possible to calculate Â for a given sample. The value of Â is determined as the angle having the following cosine and sine:

$$\cos \hat{\mathrm{A}} = \frac{\mathrm{X}}{\mathrm{R}}, \tag{4}$$

and

$$\sin \hat{\mathrm{A}} = \frac{\mathrm{Y}}{\mathrm{R}}. \tag{5}$$

“Rayleigh’s *z*”(Zar 1999) is then calculated for testing the null hypothesis of random swim directions:

$$z = nR^2. \tag{6}$$

The quadrant method divides the entire sample of swim speeds into four sectors. The quadrants are labeled Q1 through Q4, starting with Q1 in the upper right and working clockwise to Q4 in the upper left. Swim directions between 0 and 89 degrees are assigned to Q1, 90 through 179 degrees are pooled into Q2, etc. We will denote the number of schools swimming in a certain quadrant, X, as NX. Palka and Hammond (2001) modeled the effect of swim direction on sightability, with an underlying assumption that it is harder to detect animals that are swimming in such a way as to present a head/tail-on view as opposed to a full side-view profile. They concluded that (N3 / N1) was the key ratio for determining attraction or avoidance to the trackline. A Chi-squared test was performed on these two quadrants unless the number of sightings in a given quadrant was less than 5, in which case the exact binomial test was used (Palka and Hammond, 2001). If the relationship was significantly different from random, attraction was concluded if N1 was greater and avoidance was concluded if N3 was greater. We also performed a simple Chi-squared analysis on (N1+N2) versus (N3+N4), testing for non-random difference between swim directions towards and away from the trackline.

Resighting data

After the initial sighting of a dolphin school, the ship usually turned toward the school and approached it to identify the dolphin species. Resightings of the school were recorded at 2-4 min intervals after the initial sighting. These resightings allowed calculation of the positions of the dolphin school at subsequent times. From the time and position of the initial sighting and the time and position of the first resighting, we calculated swim speed and direction of the dolphin school. Again, all swim direction data is presented as if the sightings were on the port side of the ship. Swim directions from resighting positions were analyzed in the same way as the observer estimates of swim directions.

Helicopter data

One of the ships, the *David Starr Jordan*, carried a helicopter. As the helicopter flew ahead of the ship taking aerial photographs of dolphin schools, time and position were recorded with each photo pass. From successive positions and times, we computed swim speed and direction at various distances from the ship, before observers saw the schools from the ship. We estimated the ship's position at the time of each photo pass by interpolating between known ship positions and times along the transect line. Only sightings of spotted, spinner, mixed spotted/spinner and coastal spotted dolphins were investigated. And of these, only schools with which there were at least two positions of a school determined by the helicopter before the school was seen by the primary observer team and while the ship was on a constant course were used for relative motions plots. Only positions before the ship turned on the school and/or the primary team sighted the school were used. There were no sightings of coastal spotted dolphins that qualified under these criteria. From the positions of ship and dolphin school we calculated swim speed, swim direction and constructed relative motion plots (Au and Perryman, 1980; Hewitt, 1983).

RESULTS

Birder sightings

From 1998 – 2000 bird observers were on effort for approximately 102,100 km and made five sightings of target species (*Stenella* and *Delphinus* spp.) that were missed by the primary team. Assuming a consistent sighting rate by the bird observers, and given that they were only searching on one side of the trackline, we multiplied the number of missed sightings by a factor of 2. During this time the primary team made 272 sightings within 300 m perpendicular to the trackline. A simple and minimum estimate from these data of the percentage of target species sightings missed on the trackline is 3.6% (10/282) or g(0) = 0.964 (Table 1).

Tracker data

A tracker was on effort for approximately 6,239 km or roughly 40% of the 15,563 km of trackline covered in 1998 by the ship *Endeavor*. During this time the tracker made 16 target species (*Stenella* and *Delphinus* spp.) sightings within 300 m perpendicular of the trackline. The primary observer team detected all of these and had 52 additional sightings on the trackline that were missed by the tracker. A simple and minimum estimate from these data of the percentage of target species sightings missed within 300 m perpendicular to the trackline is 0% or g(0) = 1.0.

Observer estimates of initial swim speed and direction

The number of sightings by species (including mixed spotted/spinner schools) during which estimates of speed and direction were made ranged from 9 (unidentified spinner) to 384 (striped dolphin). For the species we investigated, observers made estimates of swim speed and swim direction for 62% of the sightings over three years. Observer estimates of swim speed, as a function of radial distance to the sighting, did not show any statistically significant evidence of responsive movement (Fig. 1). Swim speed and direction vectors were plotted and used as an aid in the initial inspection of data for apparent patterns (Fig. 2). No statistical test was performed on them.

Four of the 11 species considered showed a significant response (i.e. non-random swim directions) by the Rayleigh test (at alpha = 0.05). These were coastal spotted, eastern spinner, striped, and bottlenose dolphins (*Tursiops truncatus*). The mean swim directions were 67, 23, 352, and 70 degrees, respectively (Table 2). Where swim directions less than 180 degrees are swimming towards the trackline and greater than 180 degrees are away from the trackline. Of these four, all but one appeared to be attracted to the trackline. Striped dolphins appeared to be swimming away from the ship. Again, coastal spotted, striped, and bottlenose dolphins showed evidence for reaction to the survey ship according to the quadrant method. All three, including striped dolphins, were attracted to the trackline. Finally, coastal spotted and bottlenose dolphins appeared to be swimming towards the trackline according to our simple Chi-squared test (Table 2).

Resighting data

The number of sightings for which there were resightings ranged from 13 (long-beak common dolphin, *Delphinus capensis*) to 217 (striped dolphin). Speeds were plotted as a function of radial distance at time of sighting (Fig. 3). There was no statistically significant relationship between swim speed and initial radial distance to sightings. Swim speed and direction vectors were plotted (Fig. 4). These plots were used as an aid in the initial inspection of data for apparent patterns, and no statistical test was performed on them.

Five of the 11 species showed a significant response (at alpha = 0.05) to the research vessel according to the Rayleigh test for random swim directions. These were mixed spotted/spinner, offshore spotted, striped, short-beaked common, and bottlenose dolphins (Table 3). All were apparently avoiding the ship with mean swim directions of 347, 343, 338, 343, and 13 degrees respectively. The quadrant method showed a significant response for three of the eleven species. All of these species also had significant responses for the Rayleigh test. Mixed spotted/spinner, striped, and bottlenose dolphin schools were attracted to the ship according to the quadrant method. Offshore spotted dolphins and striped dolphins appeared to be swimming away from the trackline according to our simple Chi-squared test (Table 3).

Helicopter data

Three species groups were considered in this analysis. They were mixed spotted/spinner, offshore spotted and eastern spinner dolphins. The number of sightings for this category ranged from 8 (mixed spotted/spinner and eastern spinner) to 10 (offshore spotted). Swim speeds and directions were calculated from the first two positions recorded by the helicopter. These were before the primary observer team aboard the ship later sighted the schools. Swim speeds were plotted as a function of radial distance to the ship (Fig. 5). No statistically significant relationship was evident between swim speed and distance to the ship. Swim speed/direction vectors were also plotted to aid with the initial inspection of the data (Fig. 6).

Swim directions taken from the first two positions were tested with respect to an expected random distribution. The mean swim directions were 21, 34, and 46 degrees for mixed spotted/spinner, offshore spotted and eastern spinners respectively. Eastern spinners showed a significant response (at alpha = 0.05) to both the Rayleigh test and the simple Chi-squared test (Table 4). They appeared to be swimming away from the trackline. The other two species groups did not seem to react to the survey vessel. There were not enough samples for the quadrant method for any of these species. Relative motion plots of these sightings did not seem to indicate any consistent patterns of responsive movement (Fig. 7).

DISCUSSION

Birder sightings

There is no formal boundary to the perpendicular width of the trackline. The bird observers were instructed to search within a perpendicular distance of 300 m during an independent seabird strip transect survey. For sake of comparison we took this distance as the working definition of the trackline. We assume that g(0) for bird observers = 1. This is therefore a maximum estimate of g(0) for the primary observers. Although this estimate of g(0) was not equal to 1.0, it was very close. This is consistent with the histograms of perpendicular sighting distances, which meet the shape criteria for line transect methods (Buckland et al., 1993). If there are no biases in this sighting efficacy across surveys, analysis of population trends should not be affected.

Tracker data

Theoretically, the tracker should be able to detect dolphin schools before the primary team. This independent observer was much higher than the primary team of observers and therefore could search for animals farther from the ship. We would have expected the tracker to have at least as many sightings along the trackline as the primary observers. The opposite occurred with the primary team making 52 additional sightings on the trackline during the same time. According to some observers, it was difficult to make sightings from the tracker station. However, all tracker sightings were subsequently detected. This is further support that very few sightings are missed on the trackline.

Observer estimates of initial swim speed and direction

If responsive movement was detectable by swim speed (i.e., the animals were running from the ship before being sighted), we would expect that sightings closer to the ship would have been swimming faster on average than those farther from the ship. No such relationship was detectable from observer estimates of swim speed at the time of sighting. However, estimating swim speed and direction was difficult because dolphin schools were typically detected at 3-5 km from the ship and seen at a shallow angle. It is possible that the swim speeds within our range of distances are indicative of responsive movement. If this was the case, and we had data on swim speeds at greater distances, we would expect to see some cut-off distance where swim speeds decreased on average.

Coastal spotted dolphins seem to be attracted to the trackline for all three tests of observer estimates of swim direction. However, there is no such pattern found in the resighting data for this species. In addition to target species, bottlenose dolphin sightings were included for analysis of swim speed and direction for both observer estimates and resighting data. Anecdotal evidence suggests that this species has had a tendency to approach research vessels on past surveys in the ETP. Observer estimates of swim direction showed this species to be attracted to the research vessel (Table 2). Likewise, striped dolphins have been noted for avoiding the survey ship. Observer estimates of swim direction also showed a significant response by this species. But, different methods resulted in conflicting conclusions. The Rayleigh and the simple chi-squared tests indicated avoidance, whereas the quadrant method tested positive for attraction. The quadrant method was developed for species with smaller school sizes and more elusive behavioral patterns (harbor porpoise, minke whales and pacific white-sided dolphins off the East Coast of the United States). The species we have considered tend to travel in large schools and are associated with bird flocks. Both of these factors are important sighting cues. It could be that swim direction has little to do with the probability of detecting dolphins in the ETP, and the quadrant method is not applicable to the species with which we are concerned. We have contacted one of the authors of the quadrant method and are working to resolve this issue.

Resighting data

These assessments of swim speed and direction were more reliable than the observer estimates of initial swim speed and direction, but they were confounded by possible reaction to the change of direction of the ship after the initial sighting and also by measurement error. There are several outlying and impossibly high swim speeds as estimated from resighting positions. These are probably taken from large and/or spread out schools. The observers were instructed to take the position from the middle of the school, but with a very scattered and/or large school, there is no defined center as seen from the ship. If the position of a school was taken from a different part of the school at the time of resighting, this would account for a large distance between the two and therefore the very high swim speeds. We tried filtering out sightings where the angle between the sighting and resighting was larger than 10 or 20 degrees. But ultimately decided that all the data should be included and assumed that that these measurement errors were randomly distributed through our data set. There is no statistically significant relationship between swim speeds and radial distance to the ship at the time of sighting. This is consistent with the data from observer estimates. Responsive movement is probably best detected by analyzing swim direction data.

Resighting data on swim directions of bottlenose and striped dolphins both showed evidence of responsive movement. The resighting data on bottlenose dolphin swim direction is not consistent with that of observer estimates. However, the resighting data for striped dolphins agrees with the observer estimates of swim direction, including the mean swim direction. These dolphins appear to be consistently swimming away from the ship at the time they are sighted and probably before. The net result of this movement does not appear to be severely biased towards or away from the trackline and does not have an affect on the distribution of perpendicular distances in the sighting data (Gerrodette and Forcada, 2002).

Helicopter data

School positions taken by the helicopter represent our best data set for evaluating any reaction to the survey vessel for several reasons. There are fewer measurement errors in calculating the school's position (positions were taken by GPS over the center of the school). The schools were tracked over a period of time as the ship maintained a steady course, and the positions were taken before the schools were sighted and the ship turned. This last point is especially important because we are concerned with the assumption that there is no responsive movement before the schools are sighted. The other data sets do not provide information on this and the turning of the ship on schools may have an effect on swim directions. Tuna boats set on these species in the study area several times a year. The change in underwater noise of a turning ship may alert the animals to an impending chase.

We included coastal spotted dolphin sightings in our preliminary review of the helicopter data. However, there were not enough schools with positions before they were sighted or the ship had turned, and this species was not used in the final analysis. The Rayleigh test on swim directions showed a significant response for eastern spinner dolphins. These swim directions were calculated from the first two positions taken by the helicopter. They do not seem to agree with the general picture drawn from the relative motion plots, which do not suggest any clear pattern of avoidance for this or the other two target species groups we investigated. It should be noted that even if responsive movement is not evident within the distances surveyed by the shipboard observers and the helicopter, it is possible that such a reaction is occurring at even greater distances and therefore would be undetectable given this data. However, if there were responsive movement prior to detection, we would expect the histograms of perpendicular sighting distance to have a dearth or overabundance of sightings near the trackline (Buckland et. al., 1993). This is not the case for these three or any of the other species investigated above (Gerrodette and Forcada, 2002).

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Table 1. Birder sightings of target species missed by the primary observer team within 300 m perpendicular to the trackline. Bird observers only searched on one side of the trackline so we multiplied the number of missed sightings by two.

SPECIES NAME	Birder Sightings (x2)	Primary Observer Sightings	Percentage Missed
Mixed spotted/spinner	0	15	0
Offshore spotted	6	43	12.20%
Coastal spotted	0	31	0
Eastern spinner	0	7	0
Striped	0	98	0
Long-beak common	0	16	0
Short-beak common	0	44	0
Spinner (unidentified subspecies)	0	1	0
Spotted (unidentified subspecies)	2	14	12.50%
Common (unidentified species)	2	2	50%
Whitebelly spinner	0	0	0
Central-american spinner	0	0	0
Tres Marias spinner	0	0	0
Southwestern spinner	0	1	0
Pan-tropical spinner	0	0	0
TOTAL	10	272	3.60%

Table 2. Summary of swim direction data from observer estimates at time of initial sighting. The column under 'X^2' summarizes the results of our simple chi-square test for non-random difference between swim directions towards and away from the trackline. Under 'response', a '+' indicates significant attraction to the trackline, a '- ' significant avoidance and, if blank, then there was no significant responsive movement.

		Rayleigh Test			Quadrant Method		X^2
Species	N	Mean Direction	R	Response	N3/N1	Response	Response
Mixed spotted/spinner	109	287	0.14		1.27		
Offshore spotted	141	356	0.12		0.88		
Coastal spotted	71	67	0.31	+	0.33	+	+
Eastern spinner	38	23	0.32	+	0.5		
Striped	384	352	0.21	-	0.74	+	
Rough-toothed	51	310	0.12		1.2		
Long-beak common	34	257	0.13		1.53		
Short-beak common	221	358	0.08		0.89		
Bottlenose	240	70	0.13	+	0.62	+	+
Spinner (unid. subspecies)	9	244	0.18		2		
Spotted (unid. subspecies)	45	110	0.04		0.9		

Table 3. Summary of responsive movement tests of swim direction data calculated from resightings. Notation under 'Response' is the same as Table 2.

		Rayleigh Test			Quadrant Method		X^2
Species	N	Mean Direction	R	Response	N3/N1	Response	Response
Mixed spotted/spinner	93	347	0.33	-	0.36	+	
Offshore spotted	83	343	0.32	-	0.8		-
Coastal spotted	25	36	0.24		0.56		
Eastern spinner	23	320	0.15		0.4		
Striped	217	338	0.37	-	0.52	+	-
Rough-toothed	24	162	0.17		1.17		
Long-beak common	13	350	0.17		0.67		
Short-beak common	137	343	0.22	-	0.59		
Bottlenose	63	13	0.29	-	0.47	+	
Spotted dolphin (unid. subspecies)	35	326	0.24		1		

Table 4. Summary of responsive movement tests of swim direction data calculated from positions taken during helicopter passes before the ship sighted the schools. 'N/A' means there were not enough sightings to perform a test.

		Rayleigh Test			Quadrant Method	X^2
Species	N	Mean Direction	R	Response	Response	Response
Mixed Spotted/Spinner	8	21	0.37		N / A	
Offshore spotted	10	34	0.33		N / A	
Eastern spinner	8	46	0.61	+	N / A	+

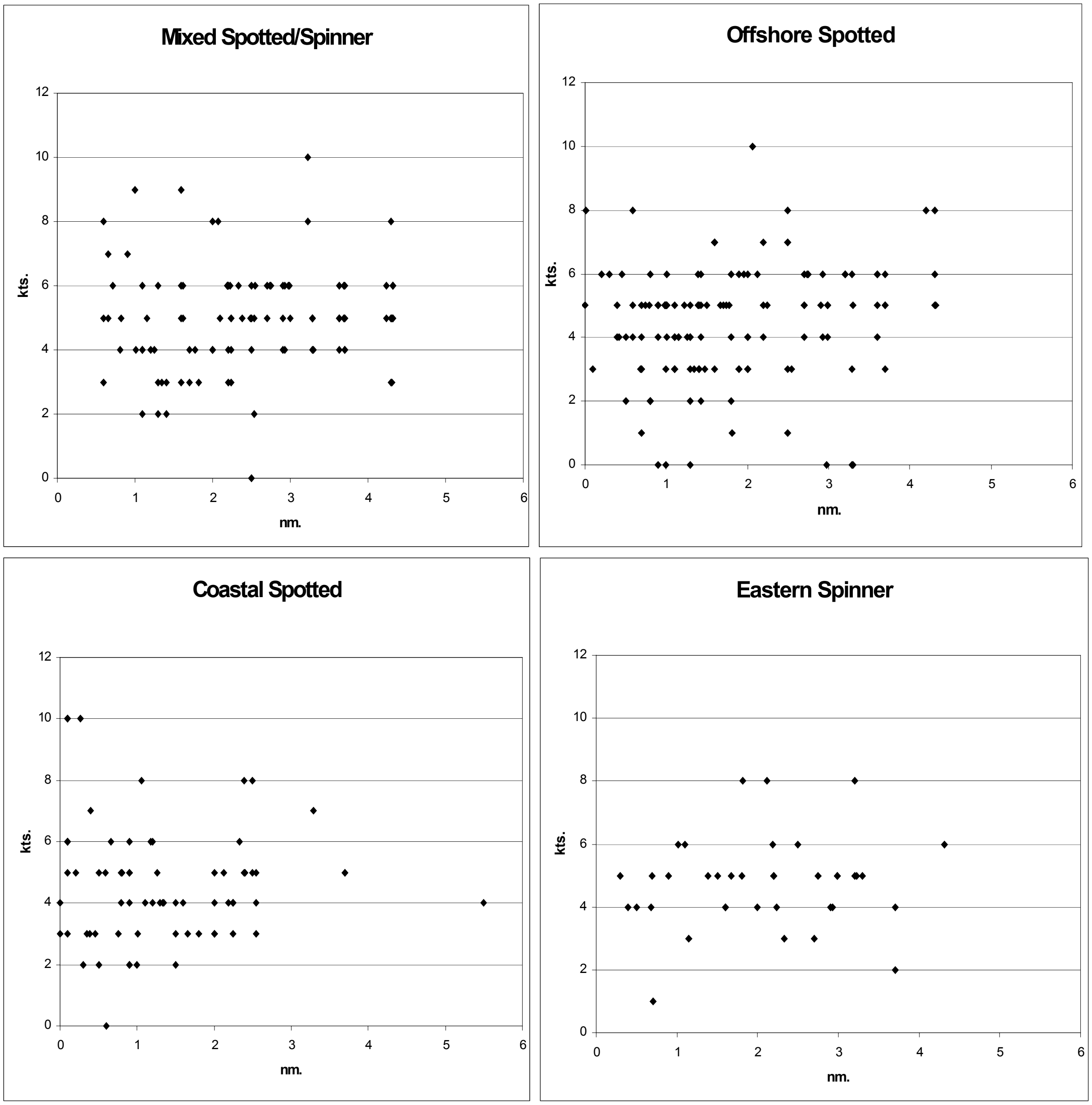
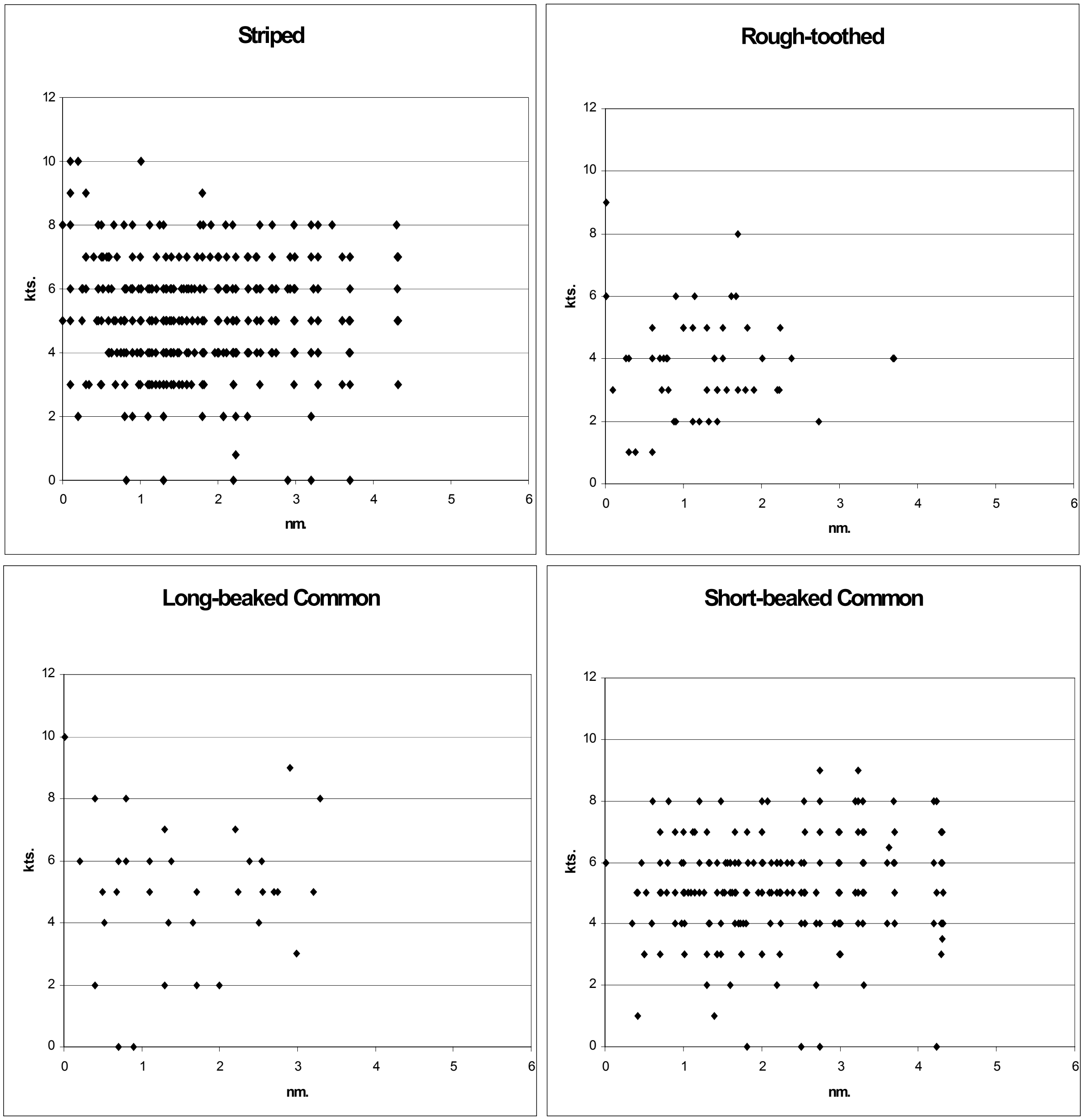


Fig. 1. Observer estimates of swim speed (kts) as a function of initial radial distance (nm) at time of sighting.

Figure 1 – *Continued*



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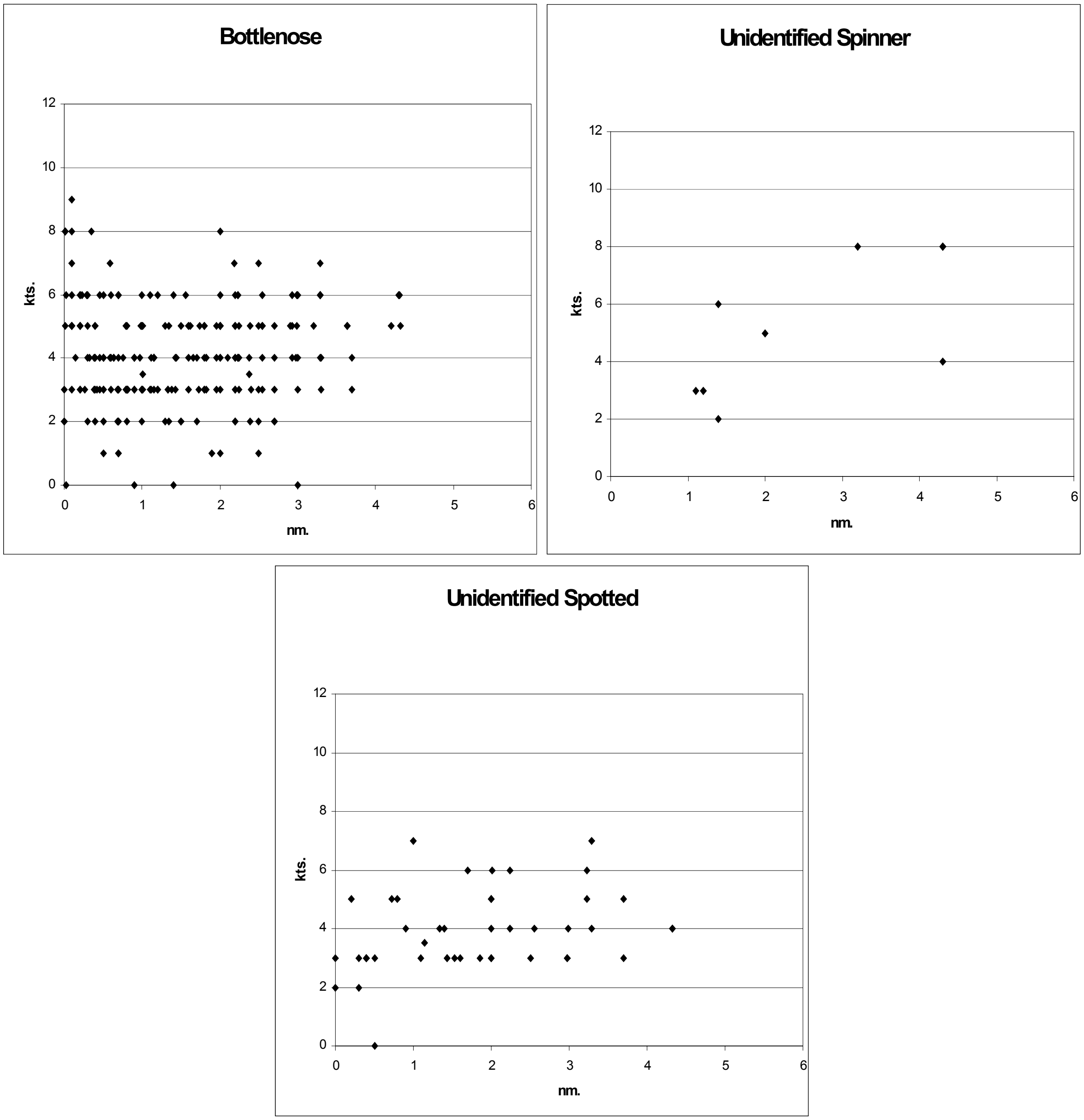


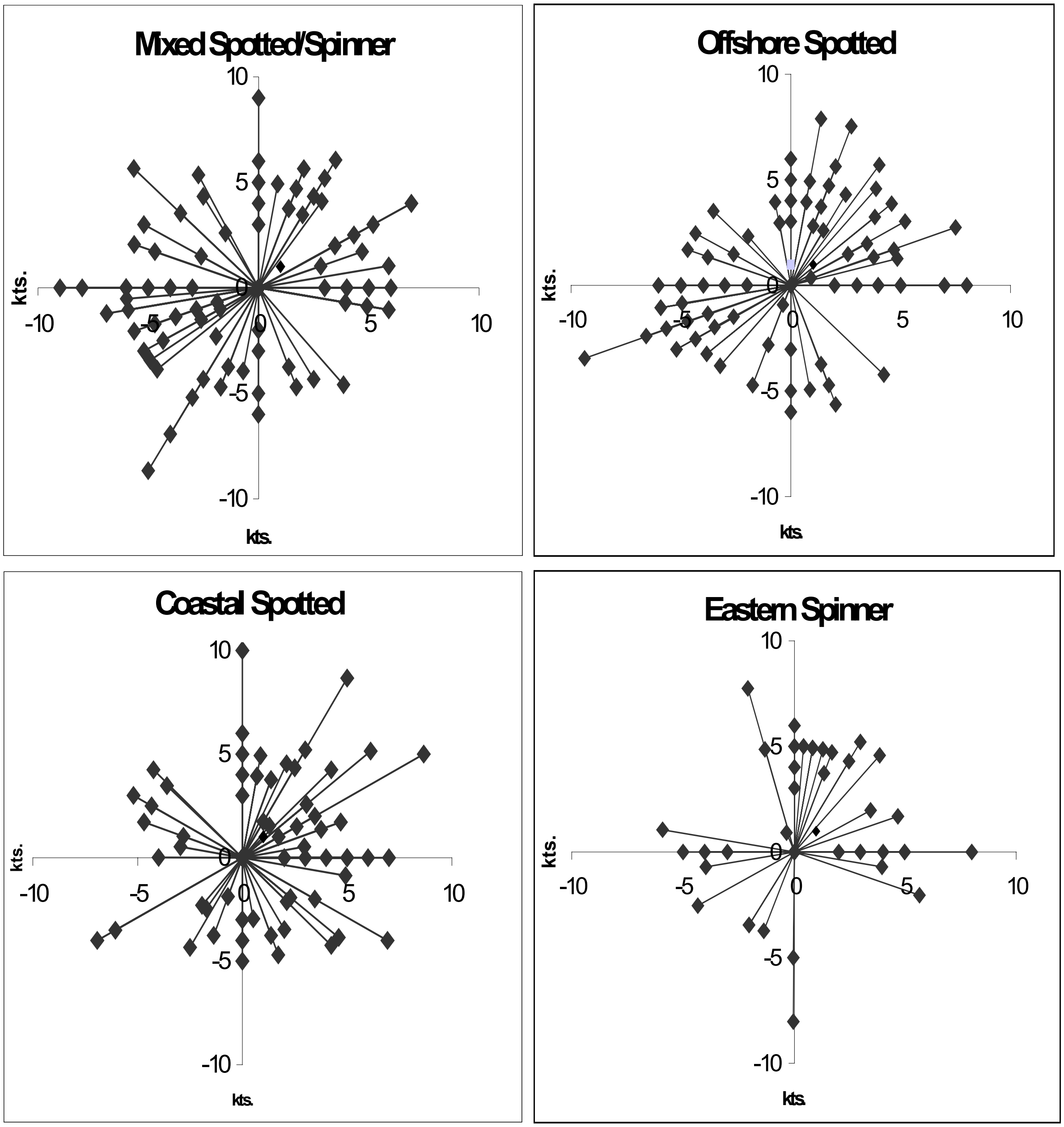


Fig. 2. Swim speed/direction vectors from shipboard observer estimates of swim speed and direction at the time of sighting. The negative x-axis represents swim direction away from the trackline and the negative y-axis represents swim directions toward the ship.

Figure 2 – *Continued*

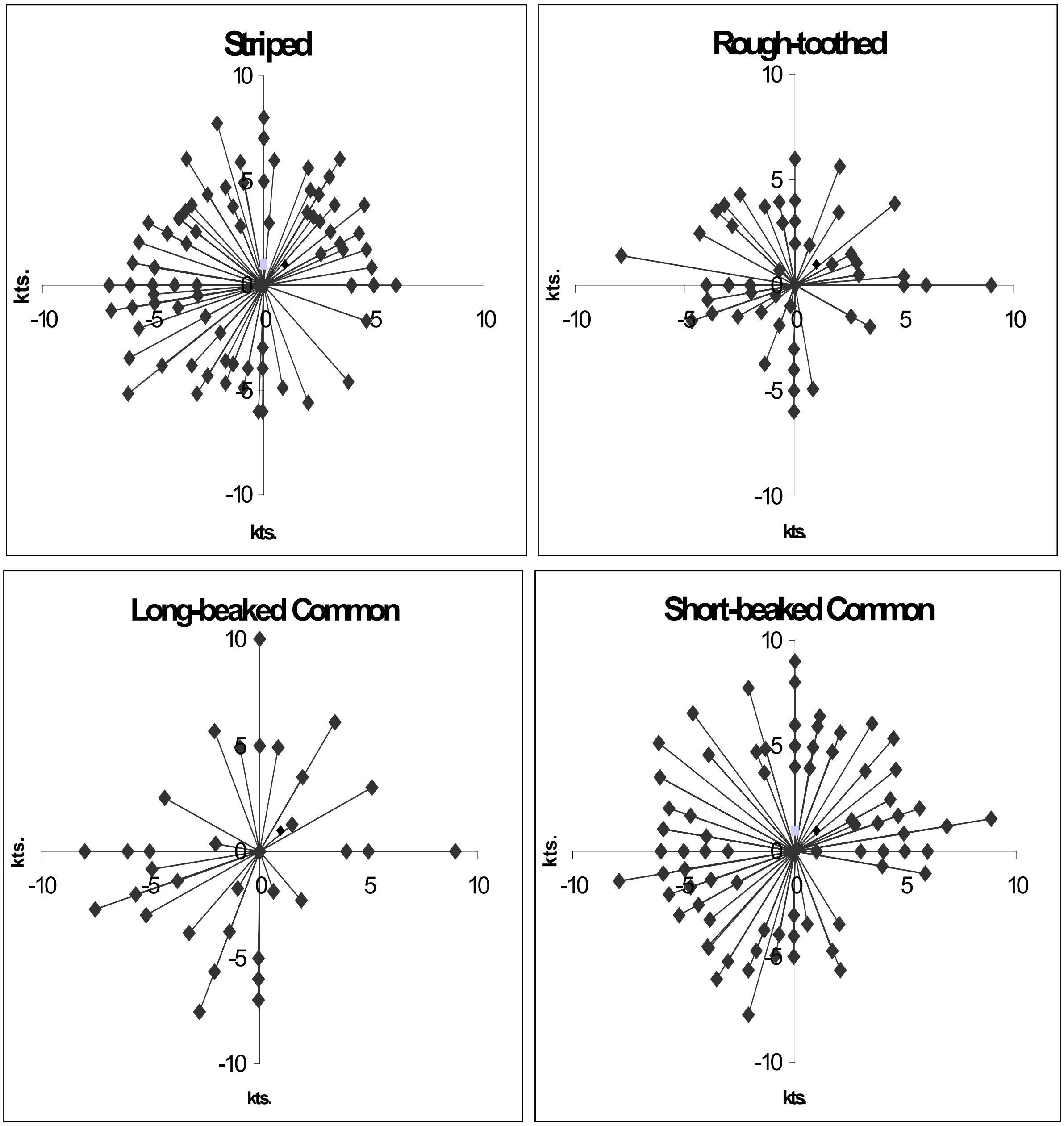
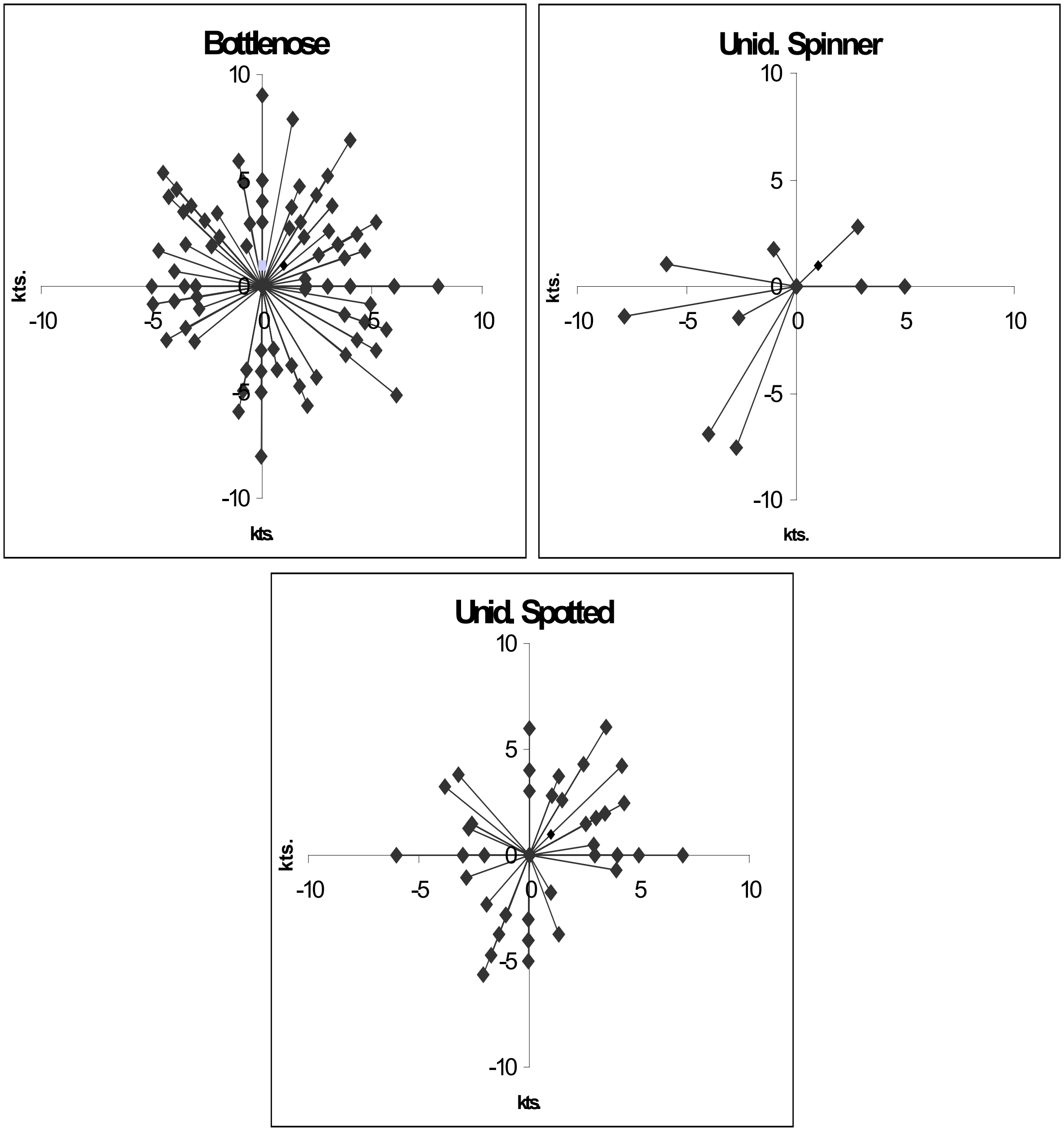


Figure 2 – *Continued*



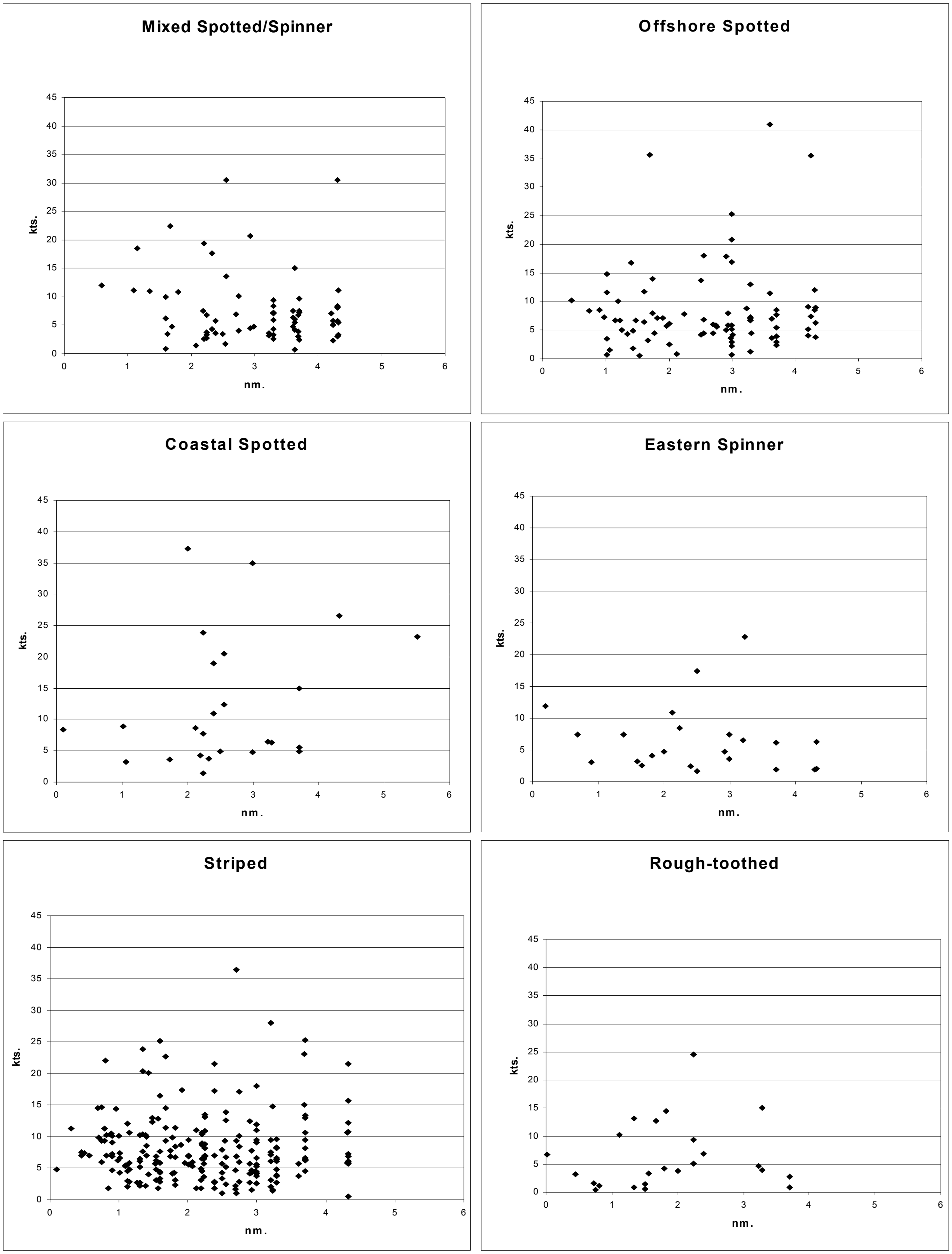
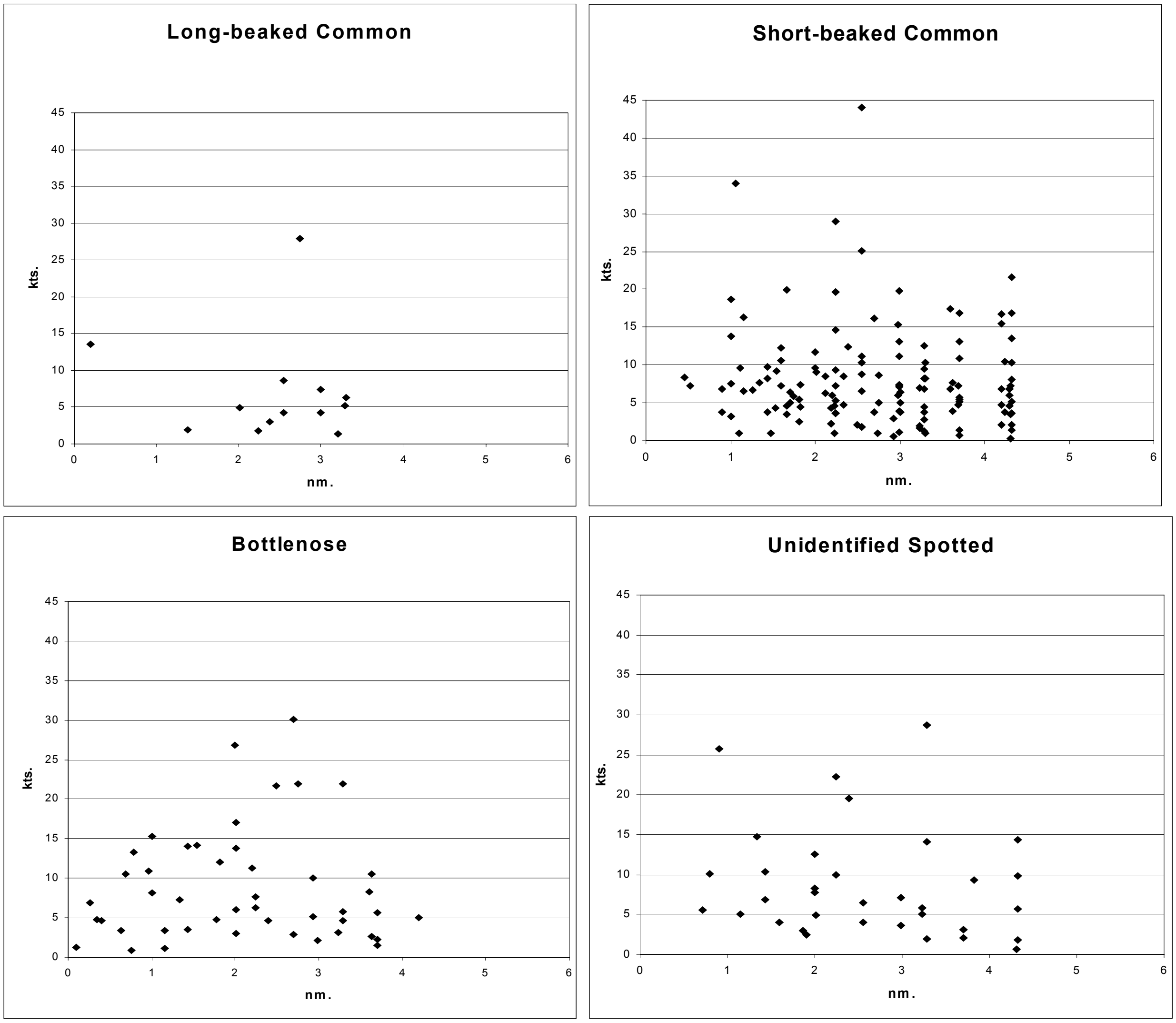


Fig. 3. Swim speed (kts) calculated from resighting positions as a function of initial radial distance (nm) at time of sighting.

Figure 3 – *Continued*



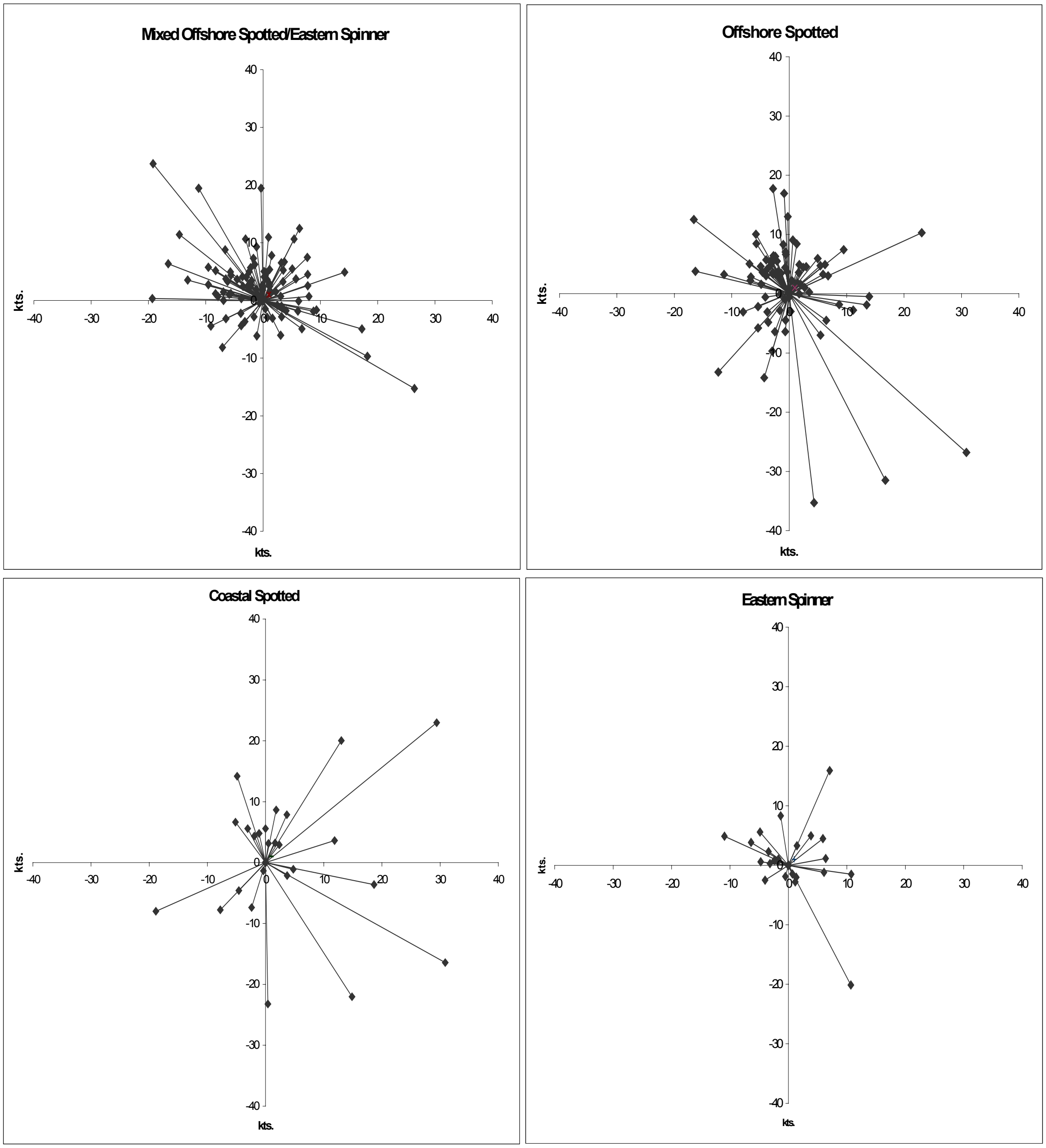


Fig. 4. Speed/Direction vectors constructed from resighting data. The negative x-axis represents swim directions away from the trackline and the negative y-axis represents swim directions toward the ship.

Figure 4 – *Continued*

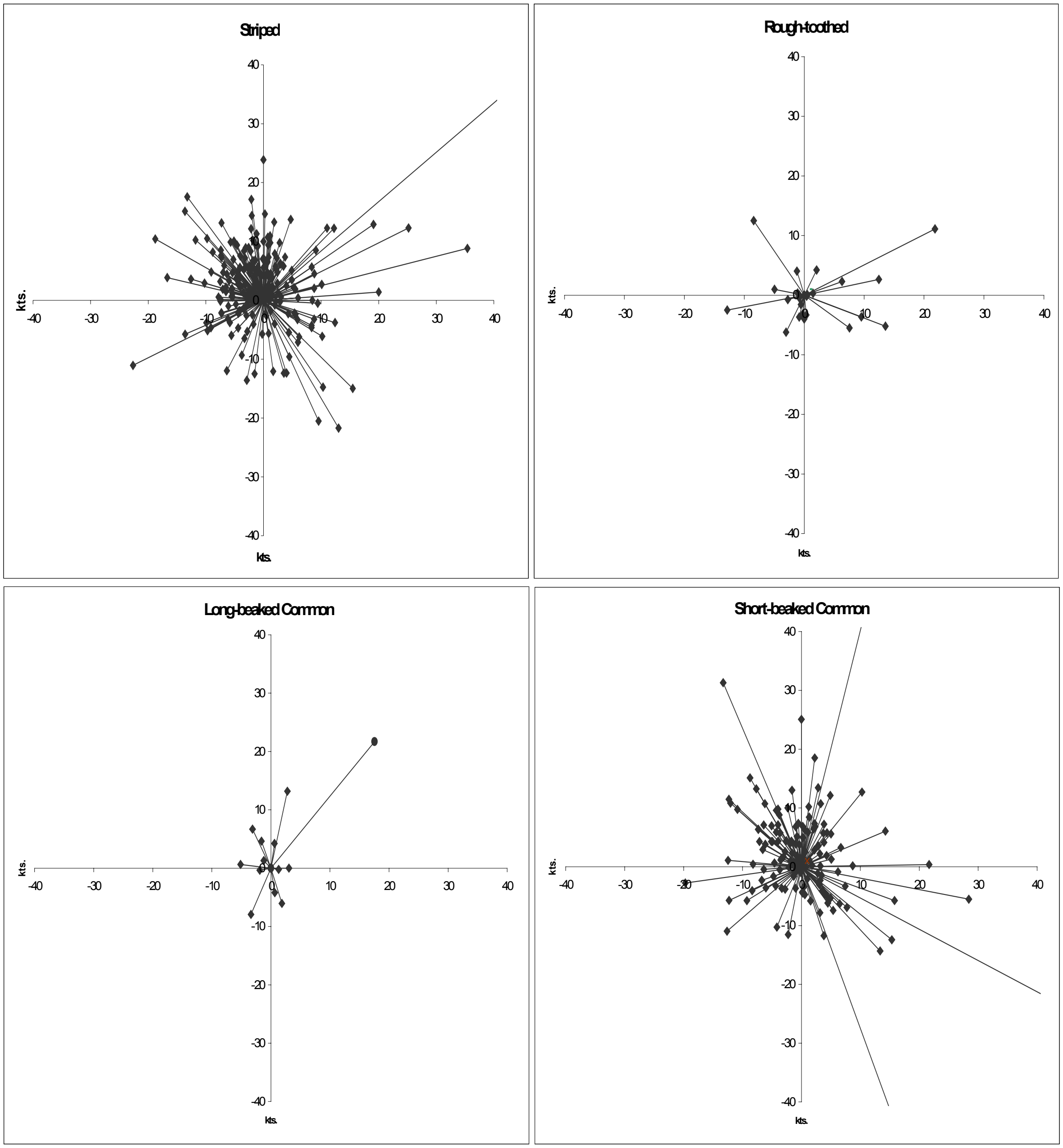
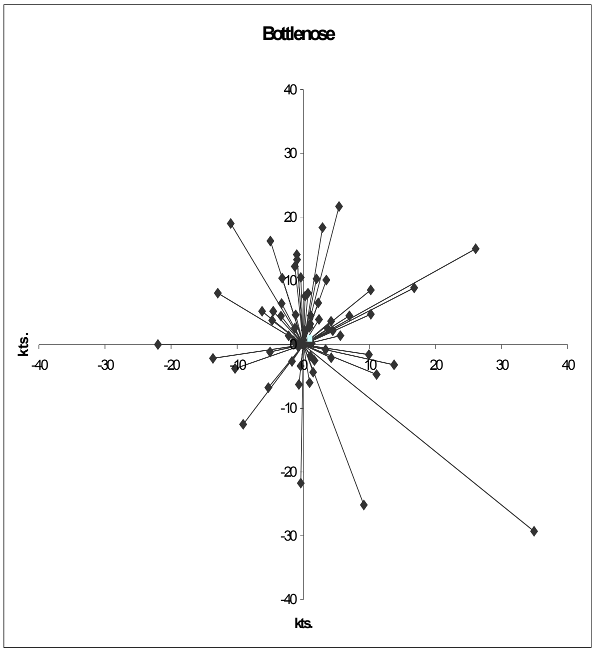
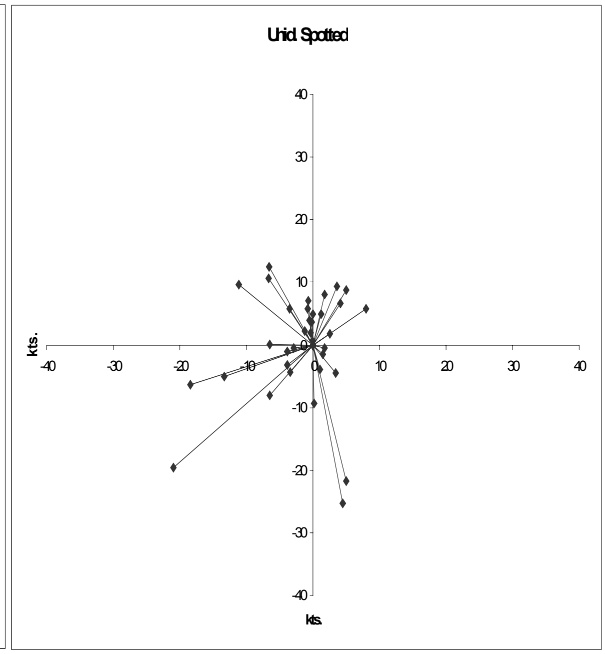


Figure 4 – *Continued*





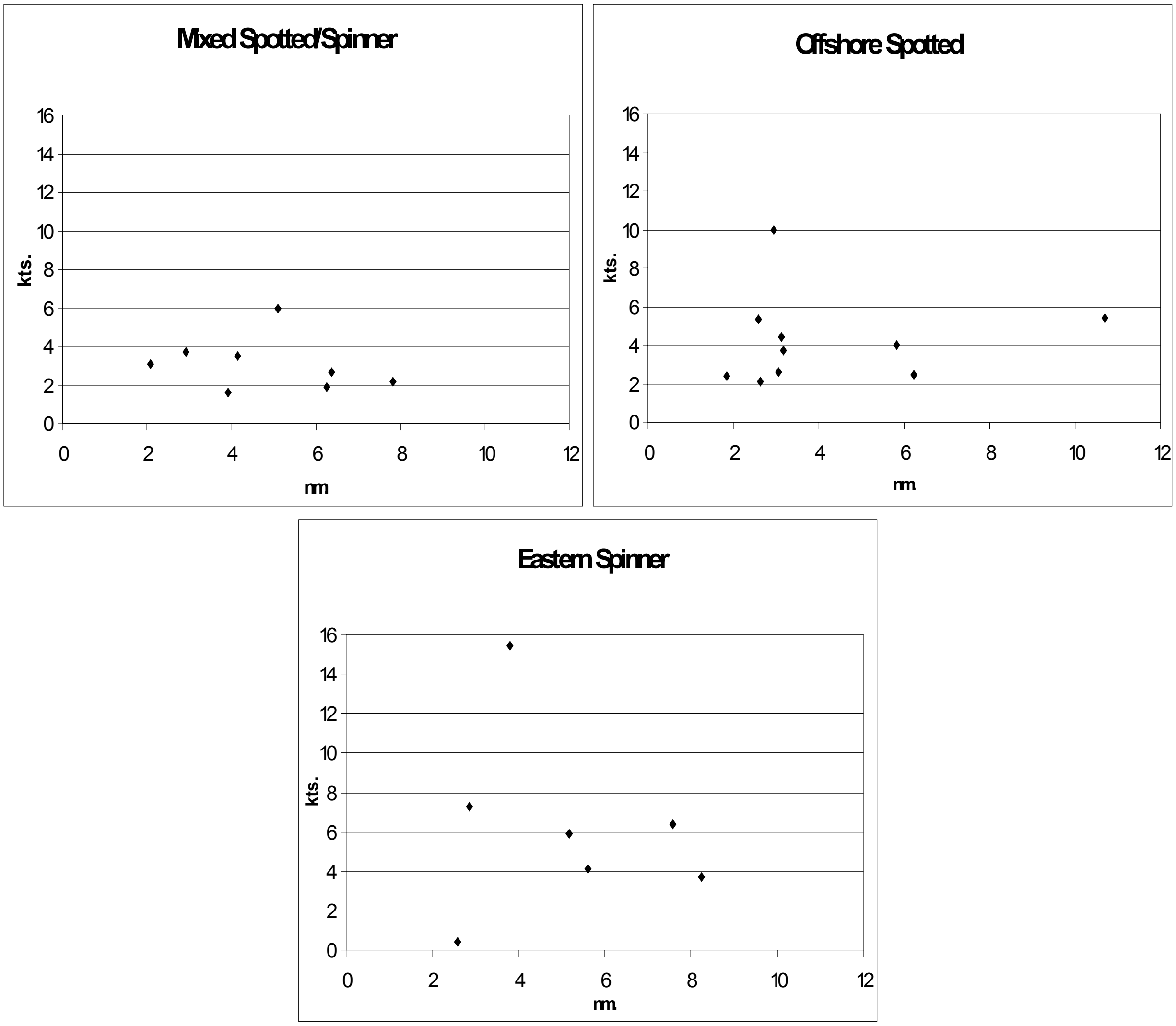


Fig. 5. Swim speeds (kts) calculated from the first two positions taken by the helicopter as a function of radial distance (nm) to the ship.

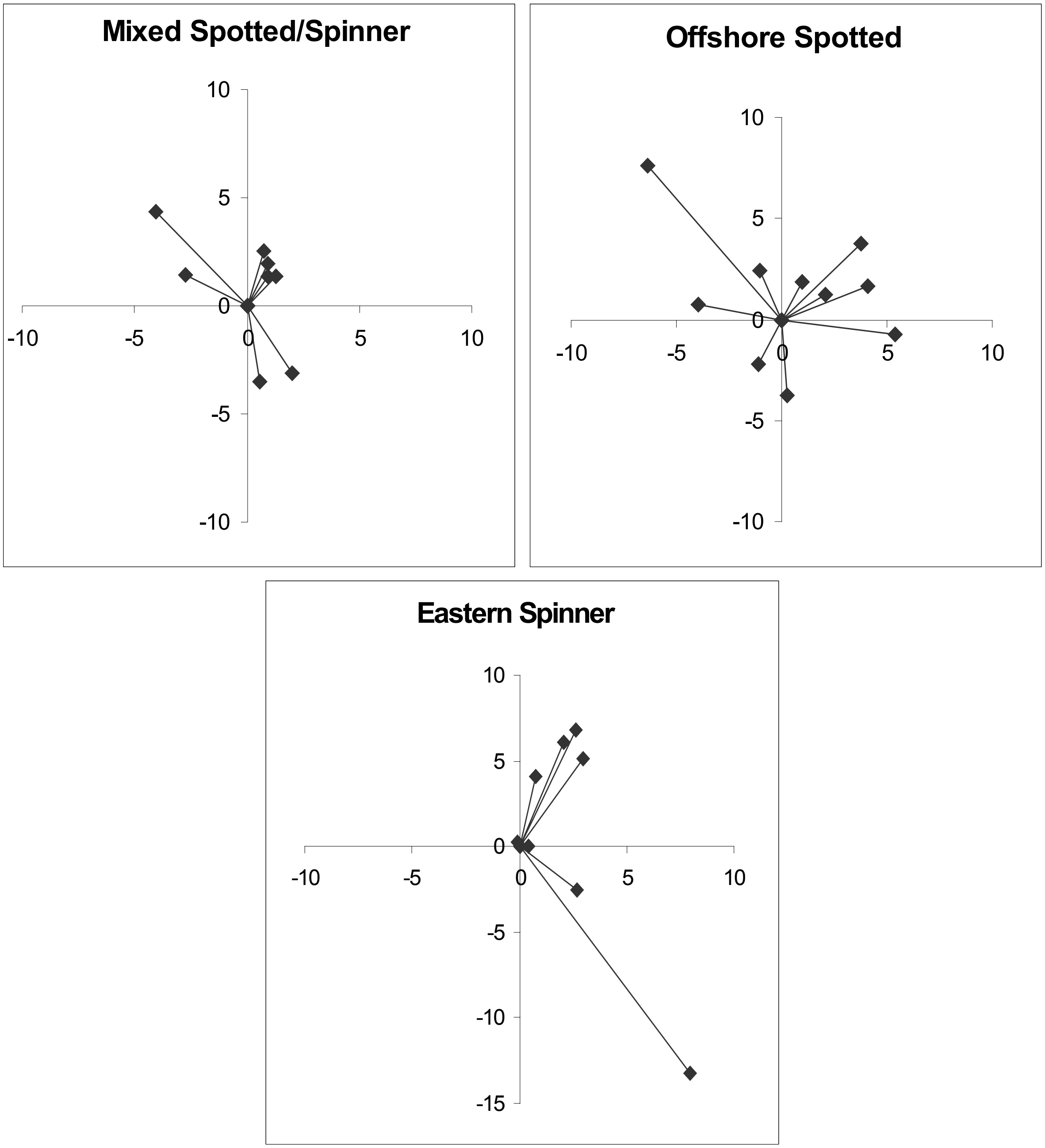


Fig. 6. Speed/Direction vectors calculated from helicopter data. Swim speeds were calculated from the first two positions of the school taken by the helicopter. The negative x-axis represents swim directions away from the trackline and the negative y-axis represents swim directions towards the ship.

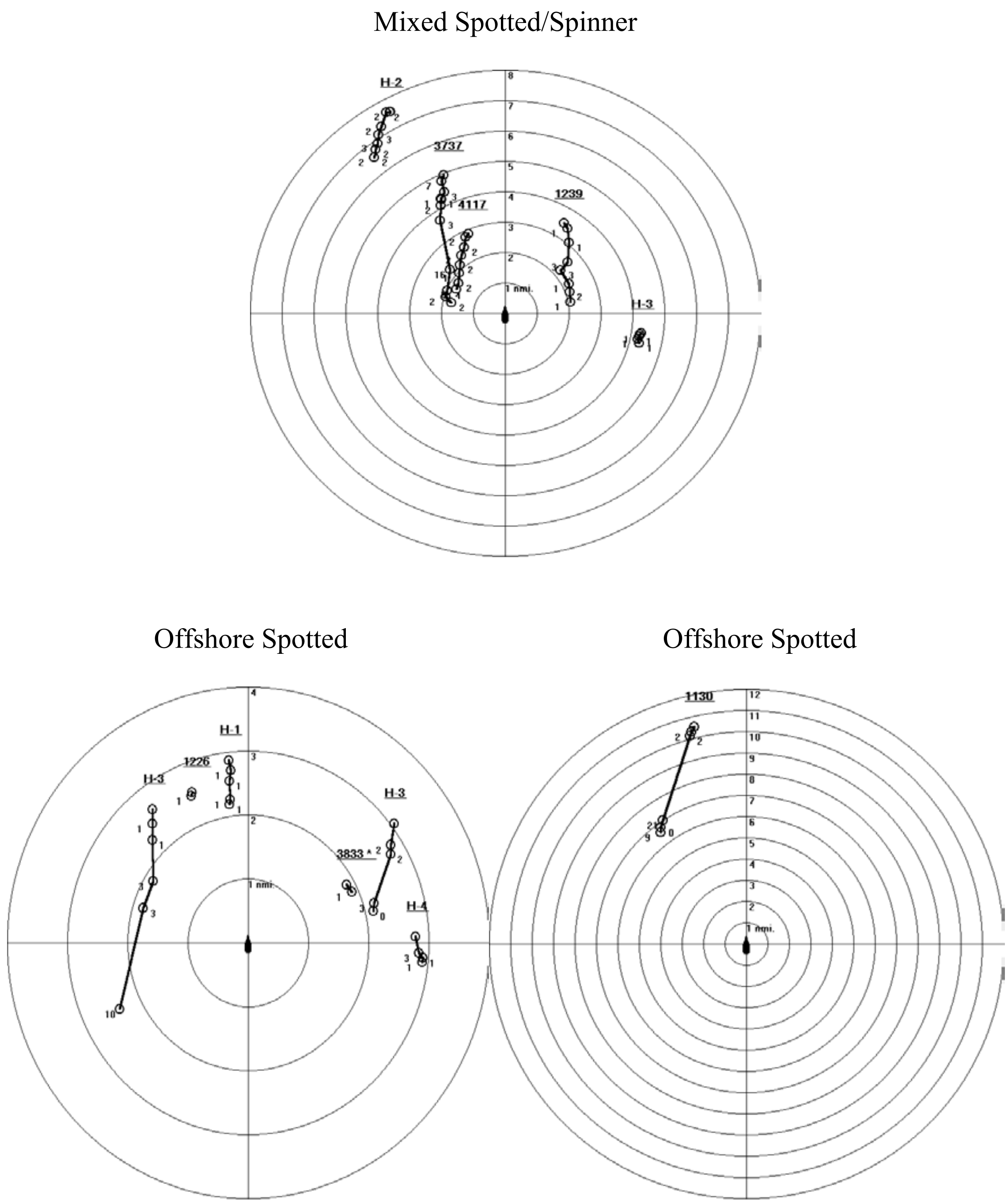
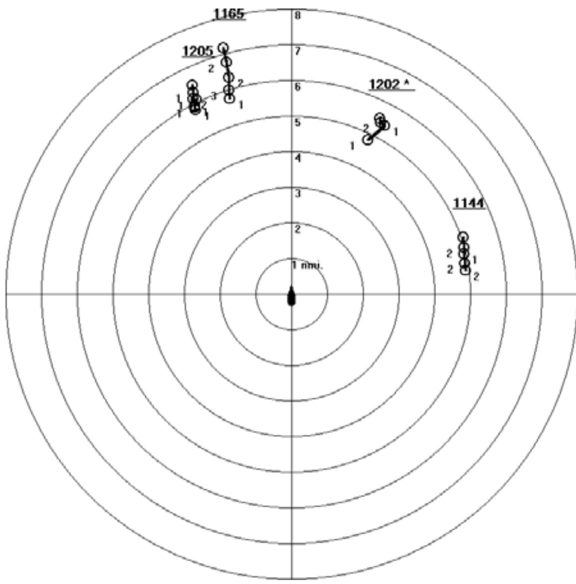


Fig. 7. Relative motion plots constructed from school positions taken by a helicopter. The sighting number is above each school. Numbers next to the positions represent elapsed time (min) after the last position. If the sighting number begins with an 'H' then the primary observer team missed the school. An asterisk (*) next to a sighting number indicates that the school's positions were flipped over the trackline to keep from overlapping plots.

Figure 7 – *Continued*

Eastern Spinner



Eastern Spinner